Population III Stars as SMBH Progenitors

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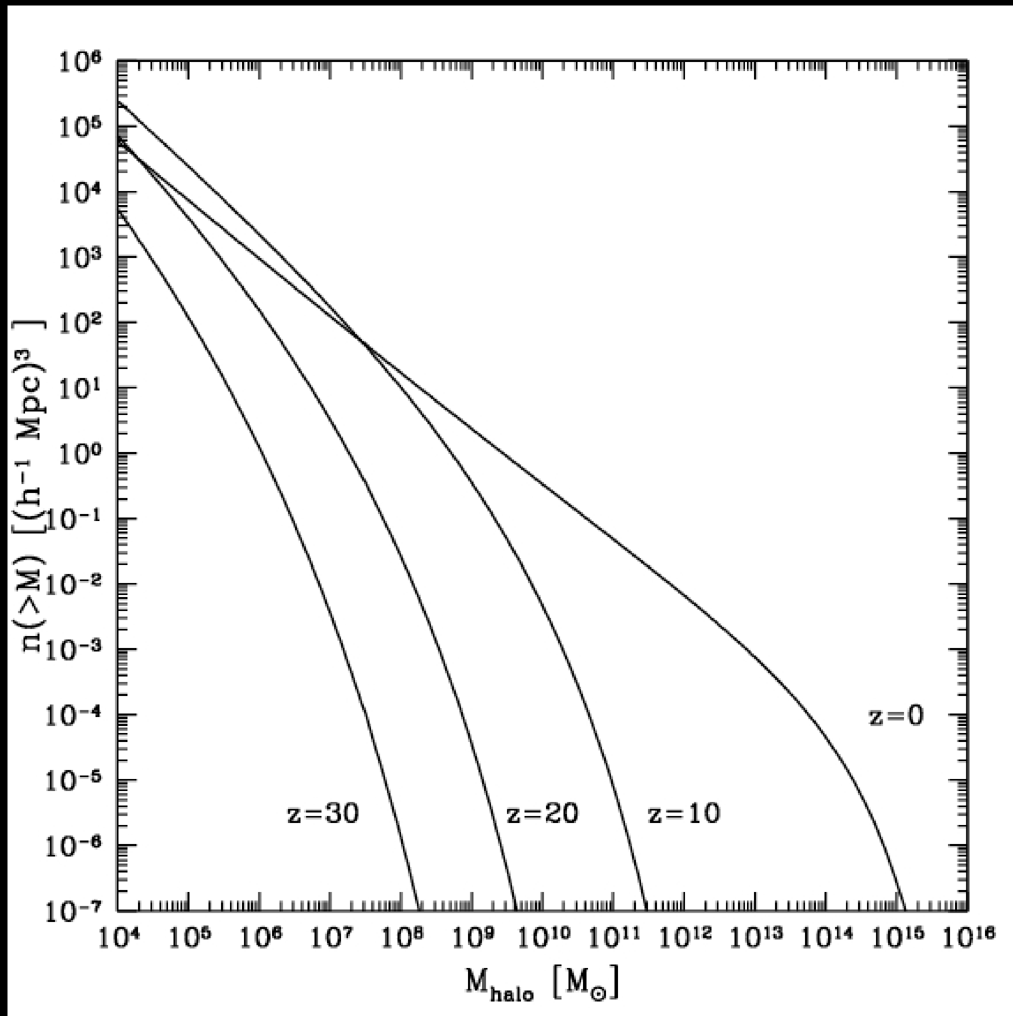
Outline

- Brief introduction
- Population III accretion rates - mass implications
- Pop III HII regions
- Pop III supernovae

Lots of Pop III stars!



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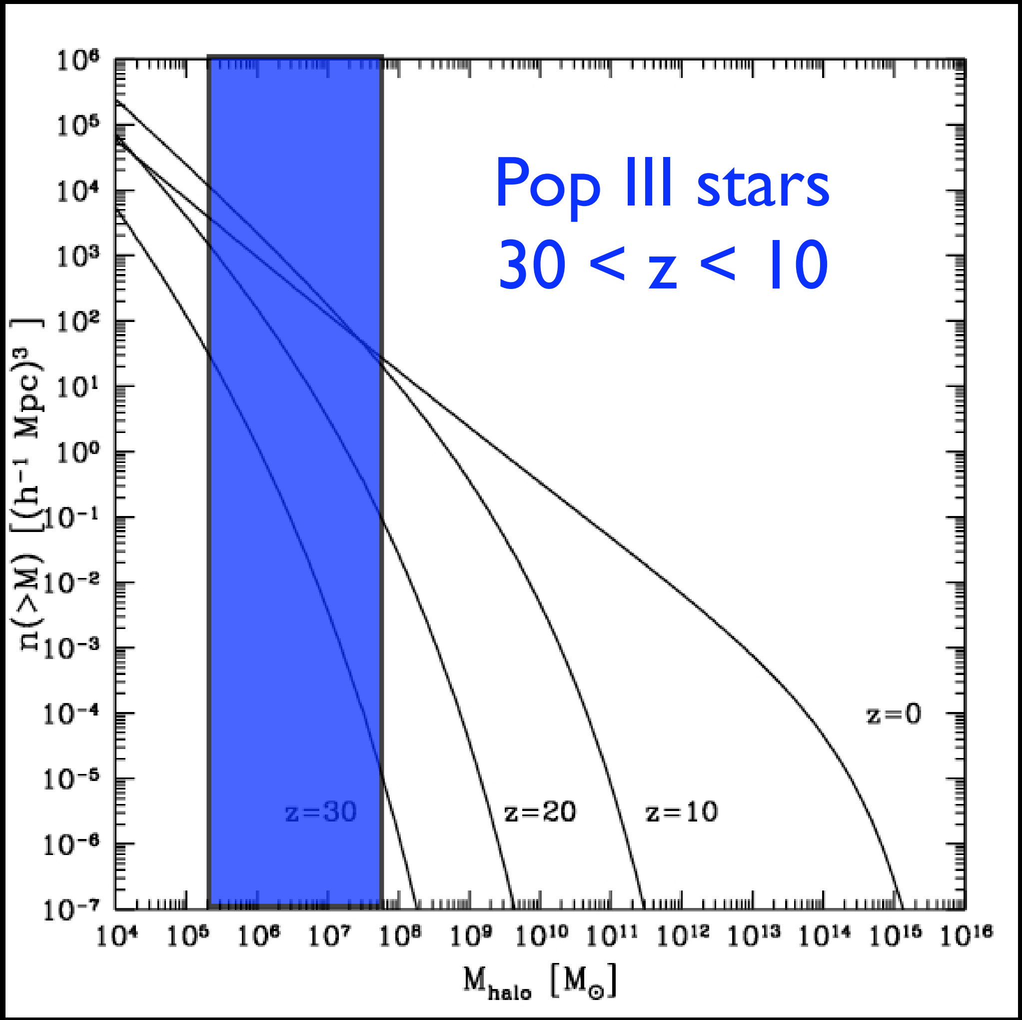
Lots of Pop III stars!



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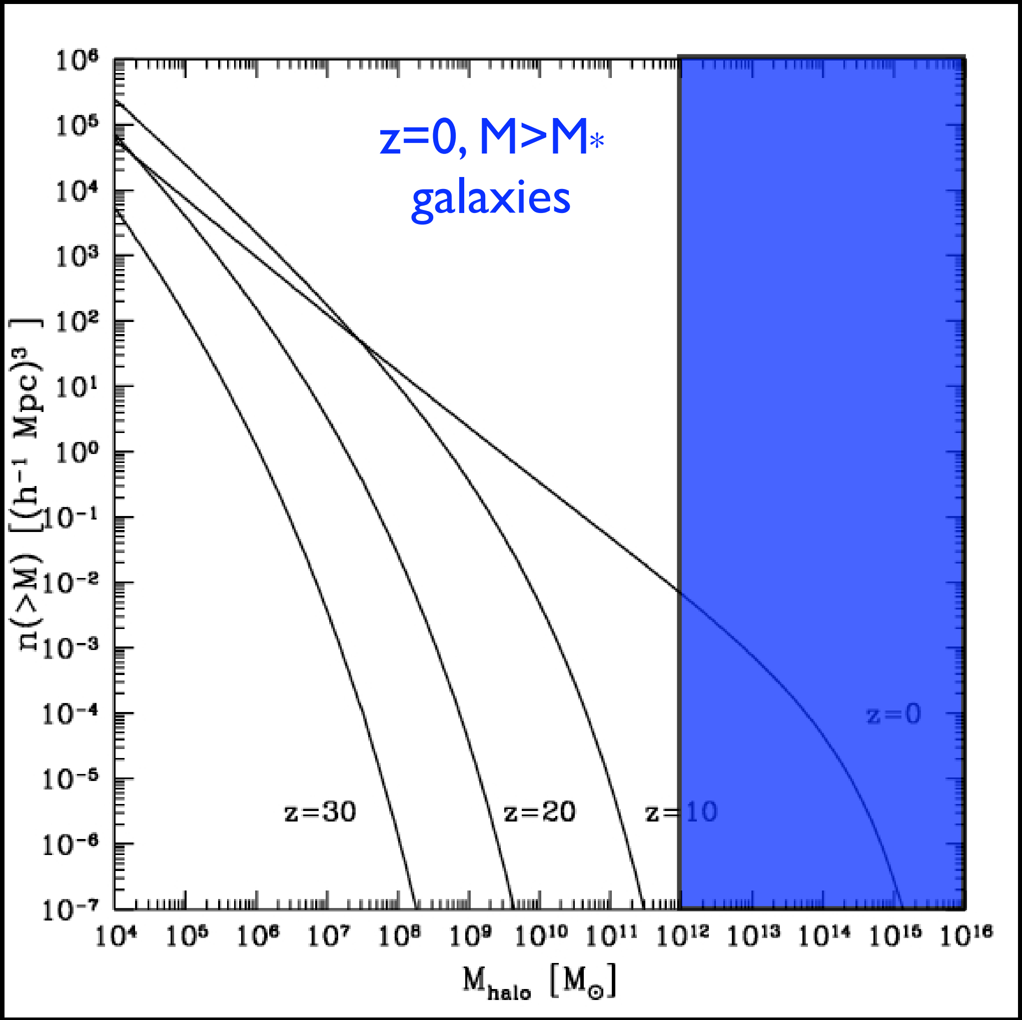
Lots of Pop III stars!



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The varied fates of Population III Stars

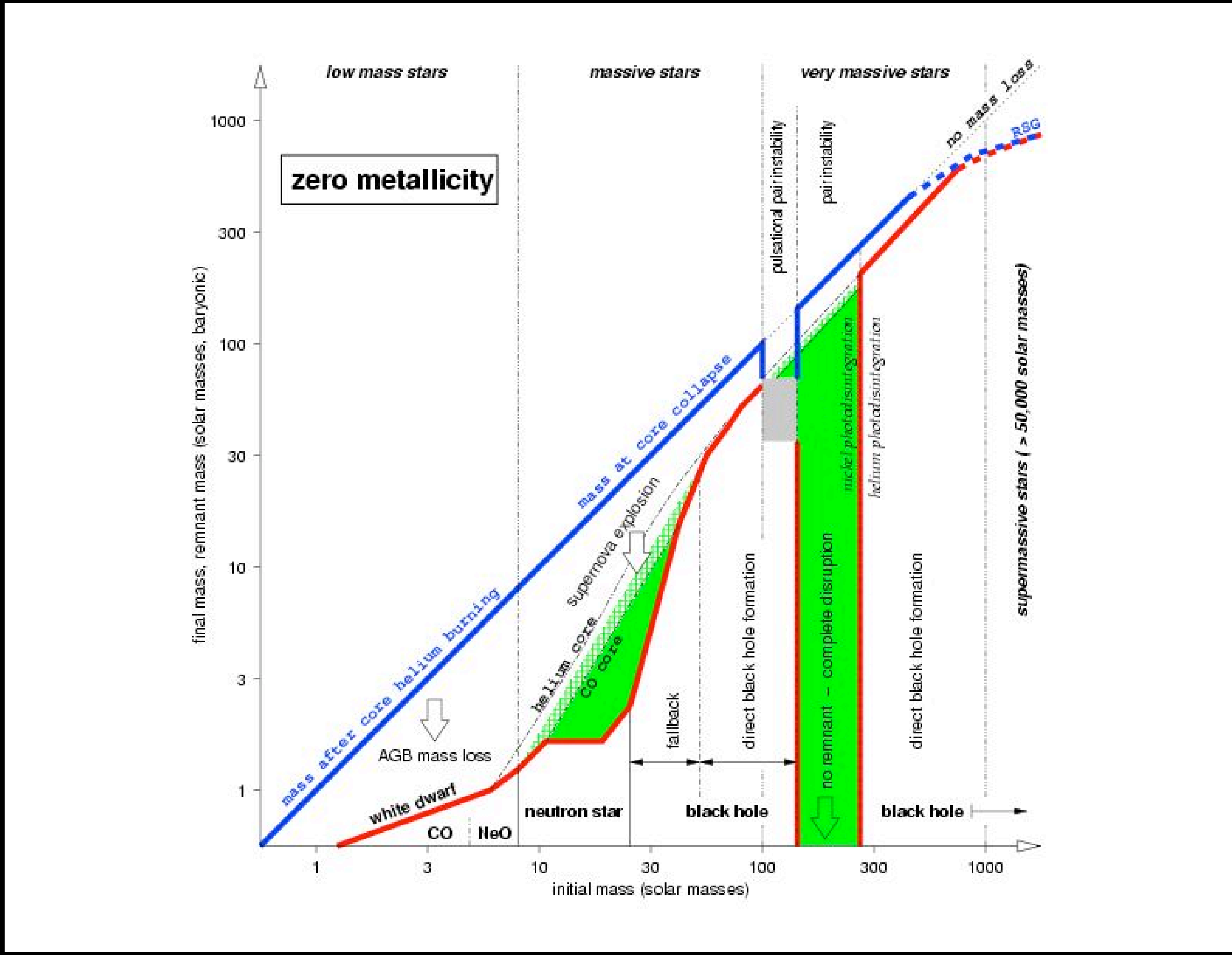

Image courtesy Alex Heger

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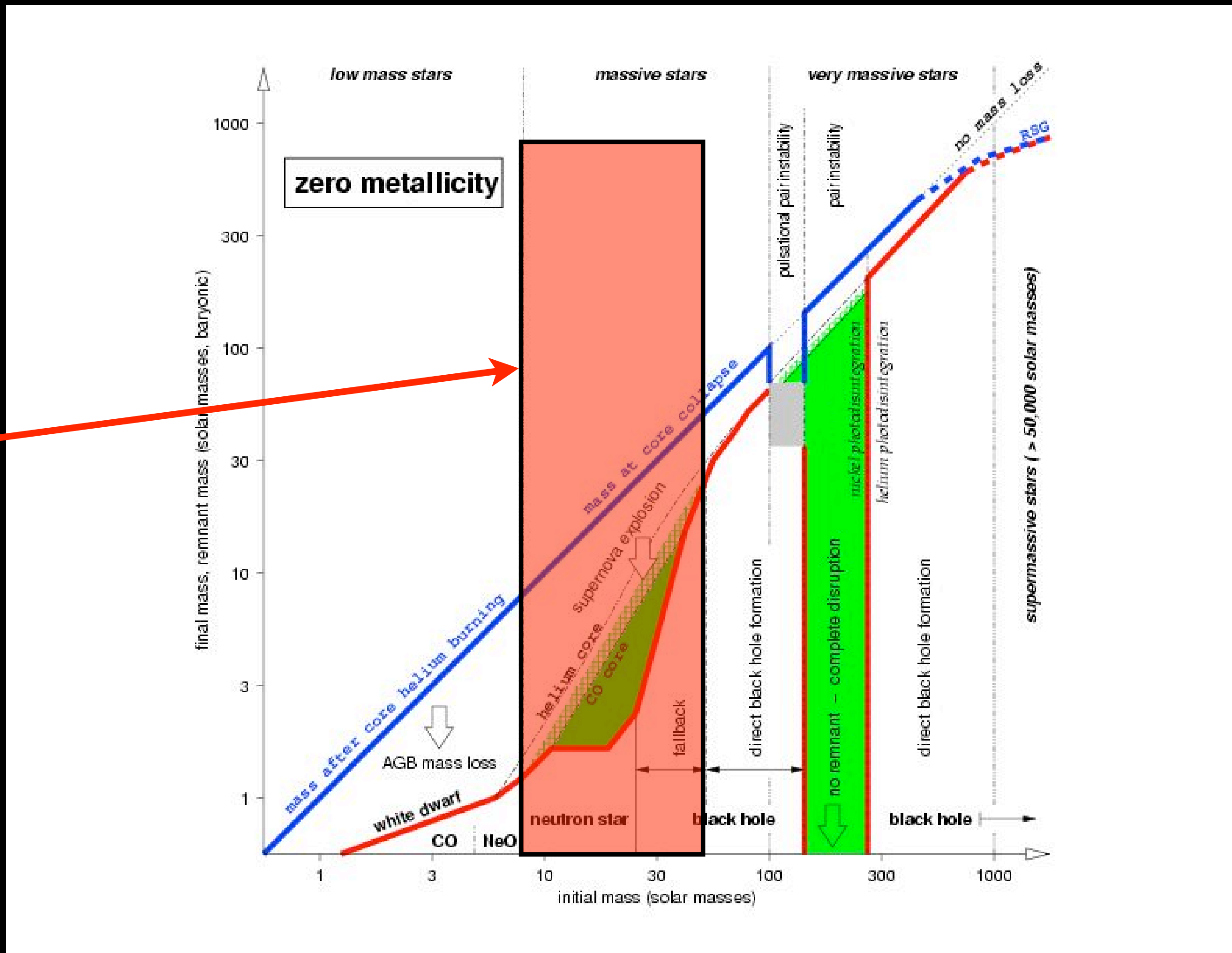
The varied fates of Population III Stars

Type II SNae



Type II
$E_{SN} \sim 10^{51}$ ergs

Image courtesy Alex Heger

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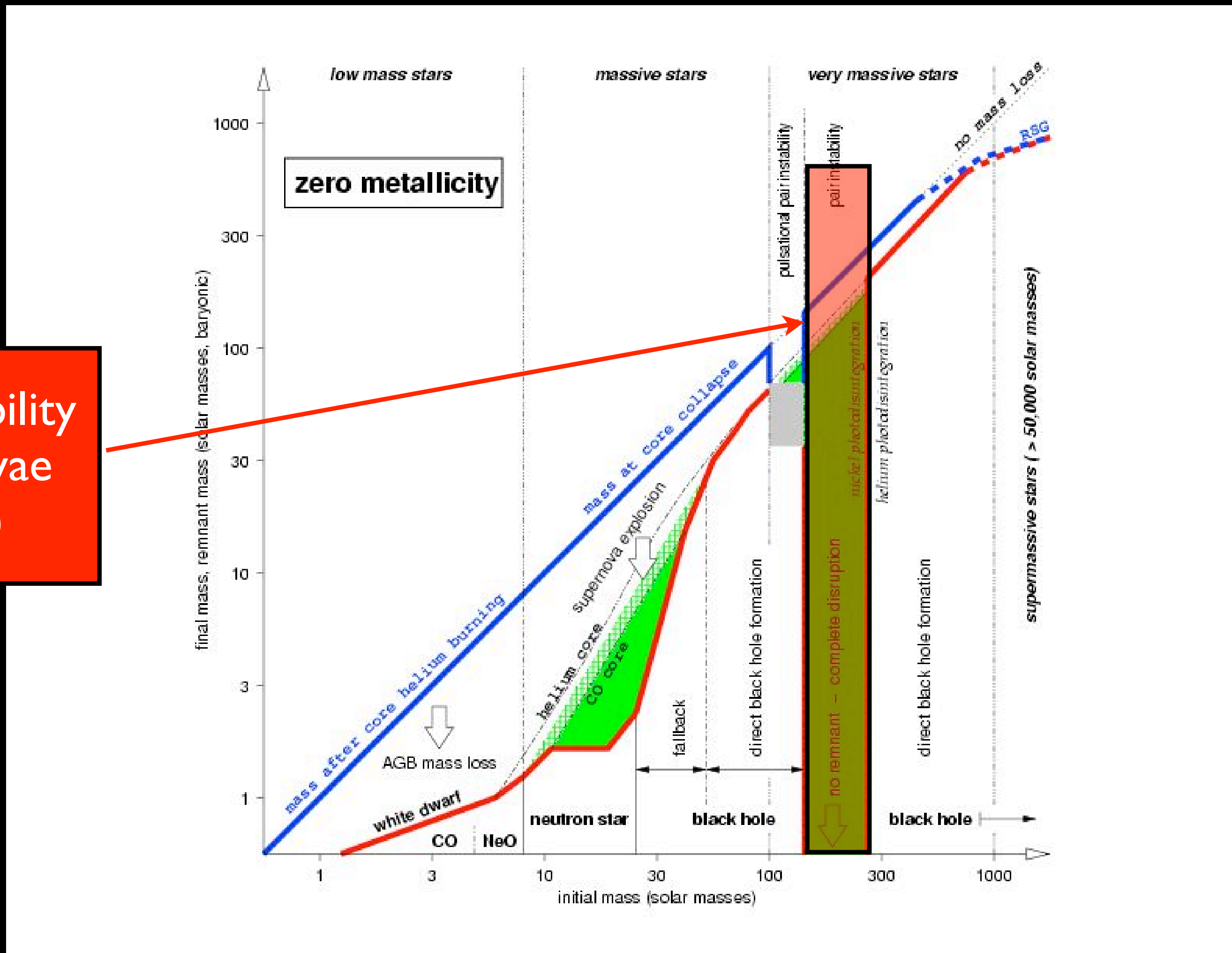
The varied fates of Population III Stars

Pair instability supernovae (PISN)



PISN
$E_{SN} \sim 10^{52}$ - 10^{53} ergs

Image courtesy Alex Heger

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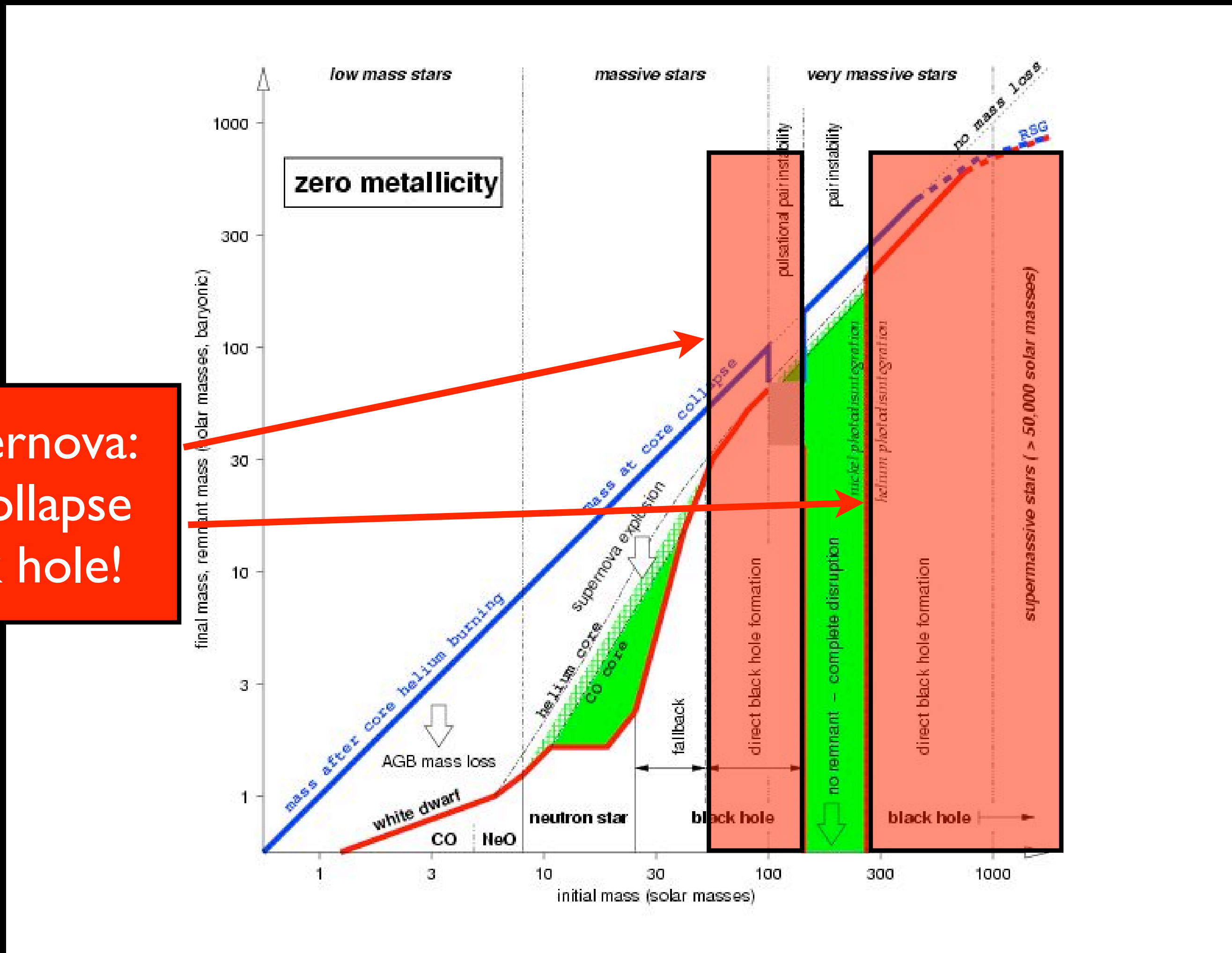

No supernova: direct collapse to black hole!

Image courtesy Alex Heger

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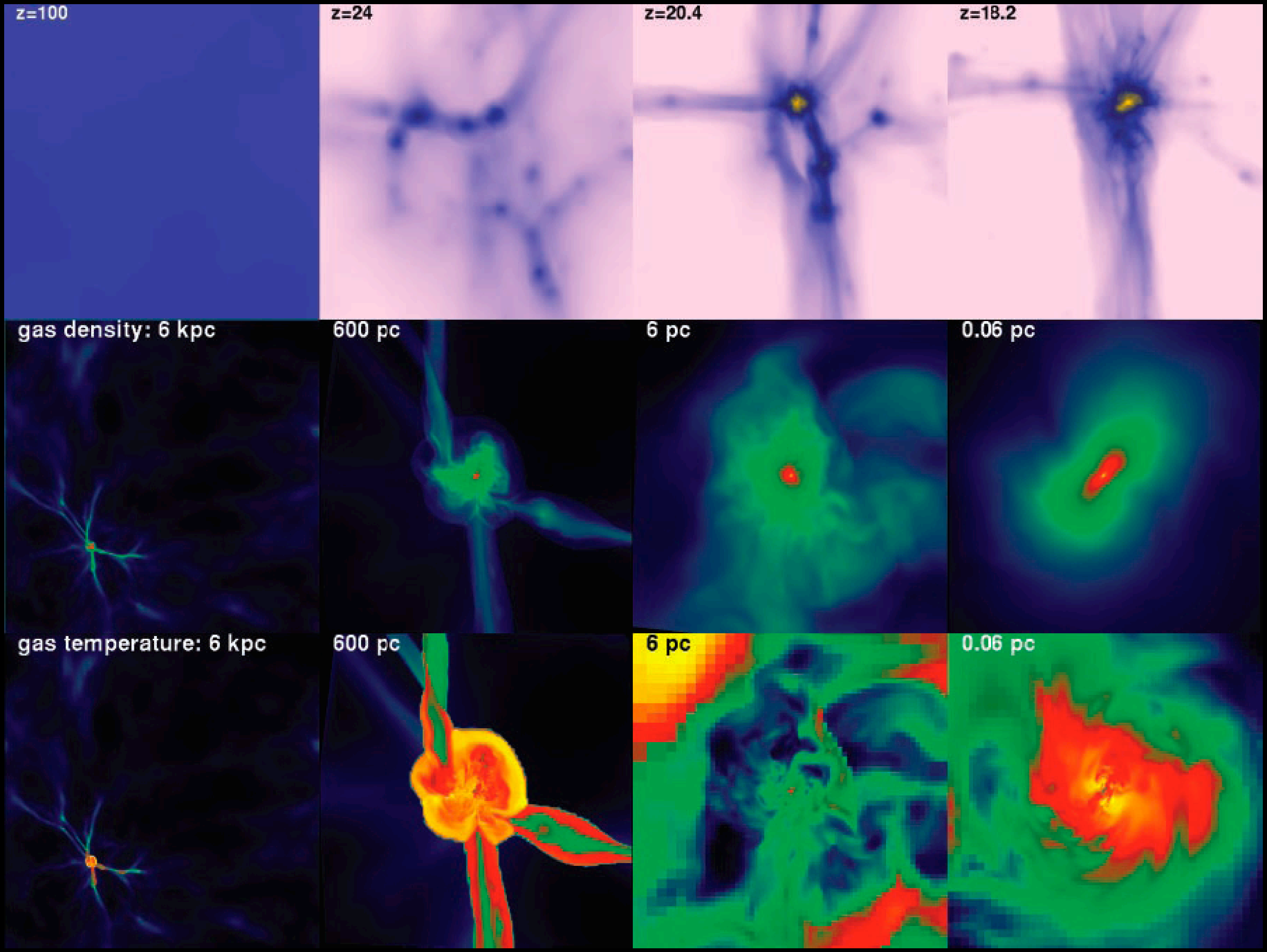
Pop III star formation: current paradigm



from Abel, Bryan & Norman, 2002, Science, 295, 93

Pop III stellar mass very uncertain!

- Theory suggests very massive stars
- Cosmological simulations concur (but only one datapoint per paper!) (Abel et al. 2002; Bromm et al. 2002; Yoshida et al. 2006)
- Inferences from halo star abundance ratios suggest <M> ~ 20-40 $M_\odot$ (Tumlinson 2006)
- Theoretical models suggest accretion onto star is very important for final mass! (Omukai & Palla 2003; Tan & McKee 2004)
- How much does accretion rate vary between simulations?

Numerical experiment

- 12 simulations, 3 volumes: 0.3, 0.45, 0.6 Mpc/h comoving boxes
- Start all sims at z=99, follow evolution of most massive halo until epoch of collapse using Enzo AMR code
- 22 levels of AMR with hydro+N-body, 9 species nonequilibrium chemistry (H, He, H_2). No UV background!
- Maximum density $\sim 10^{10}$ cm^{-3} (stop due to opacity effects)

O'Shea & Norman 2006, ApJ submitted
astro-ph/0607013

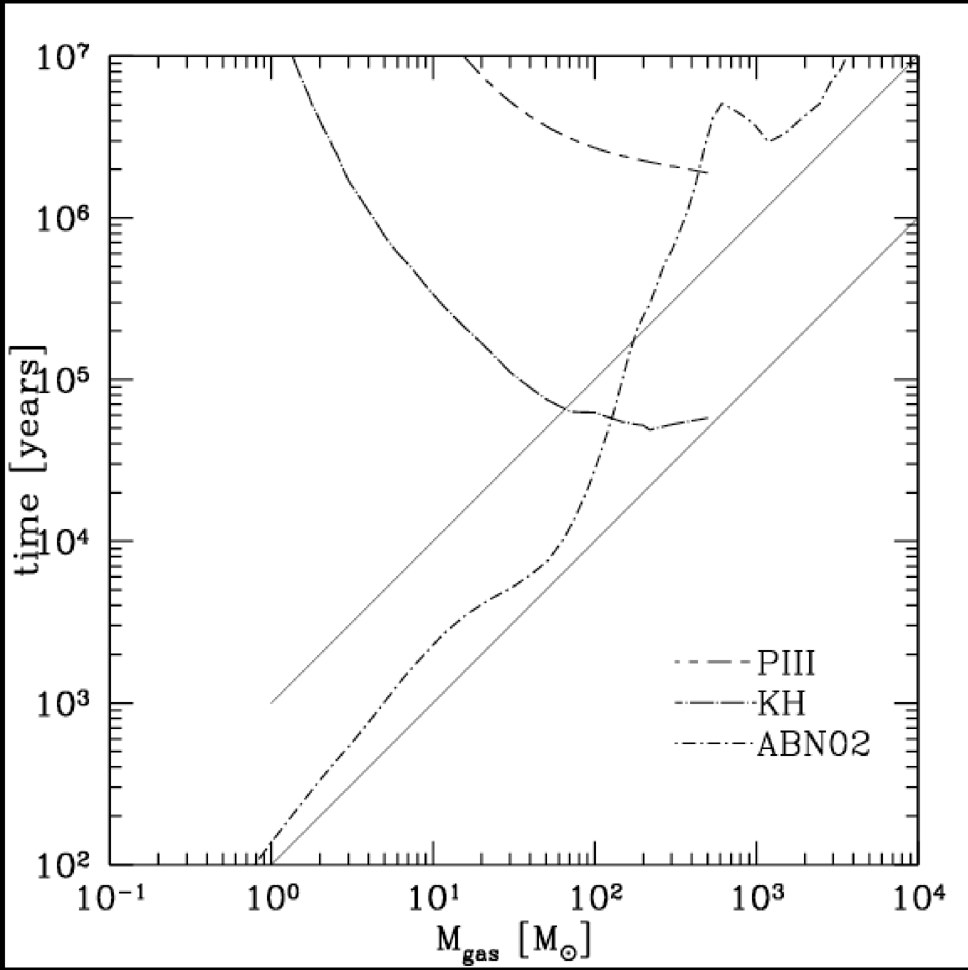
General results

- Results qualitatively similar to Abel et al. 2002, Bromm & Loeb 2004, Yoshida et al. 2006
- No signs of fragmentation observed in the halo cores of any of our 12 simulations, up to $n_H \sim 10^{10}$ cm^{-3}
- Halo virial masses do not evolve significantly with redshift: $M_{halo} \sim 1.5 - 7 \times 10^5 M_\odot$ for $33 > z > 19$
- Other bulk properties consistent with previous work

Accretion time vs. radius - all 12 sims

Accretion time

$$t_{acc} = \frac{M_{enc}(r)}{\dot{m}(r)}$$



Radius (proper pc)

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Accretion time vs. radius - all 12 sims

Accretion time

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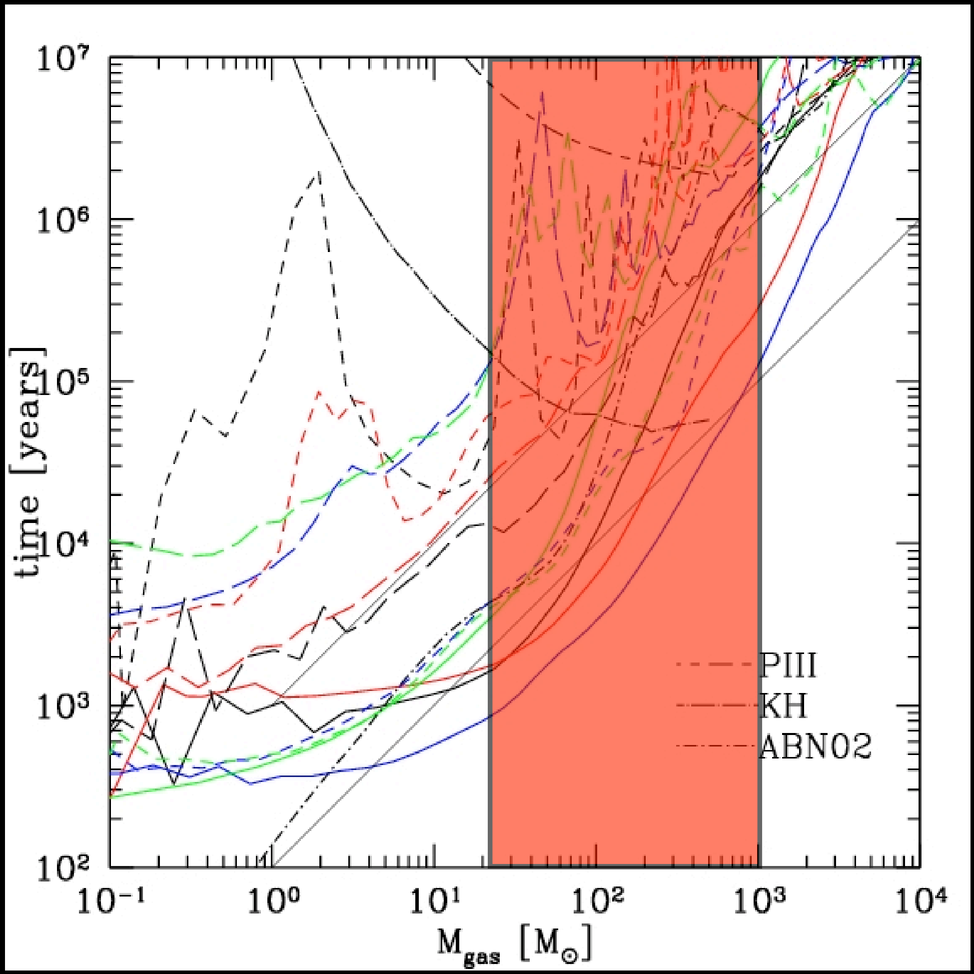

Plausible stellar mass range: ~20-1000 $M_\odot$

Radius (proper pc)

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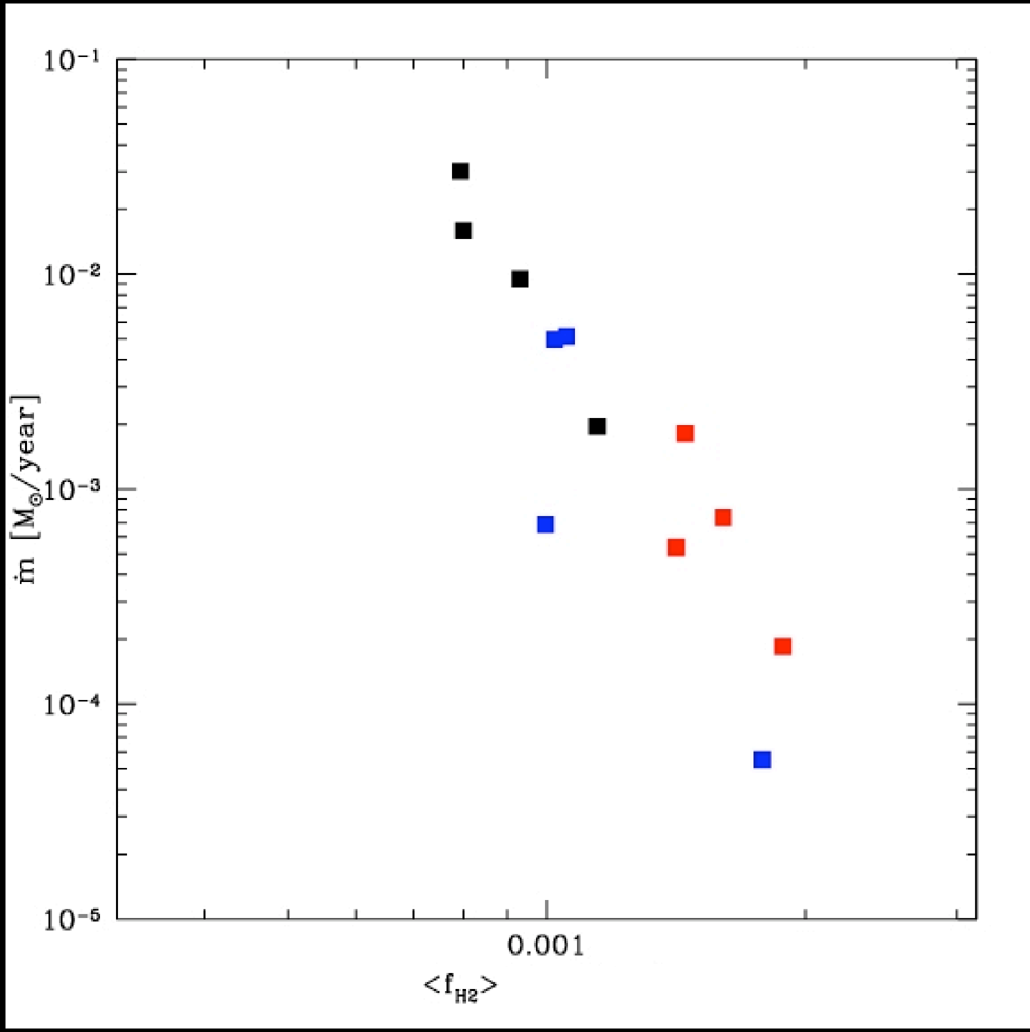
Accretion rate vs. core H_2 fraction

accretion rate

$$\dot{m} \simeq c_s^3/G \sim T^{3/2}$$



0.3 Mpc/h
0.45 Mpc/h
0.6 Mpc/h

Core H_2 fraction

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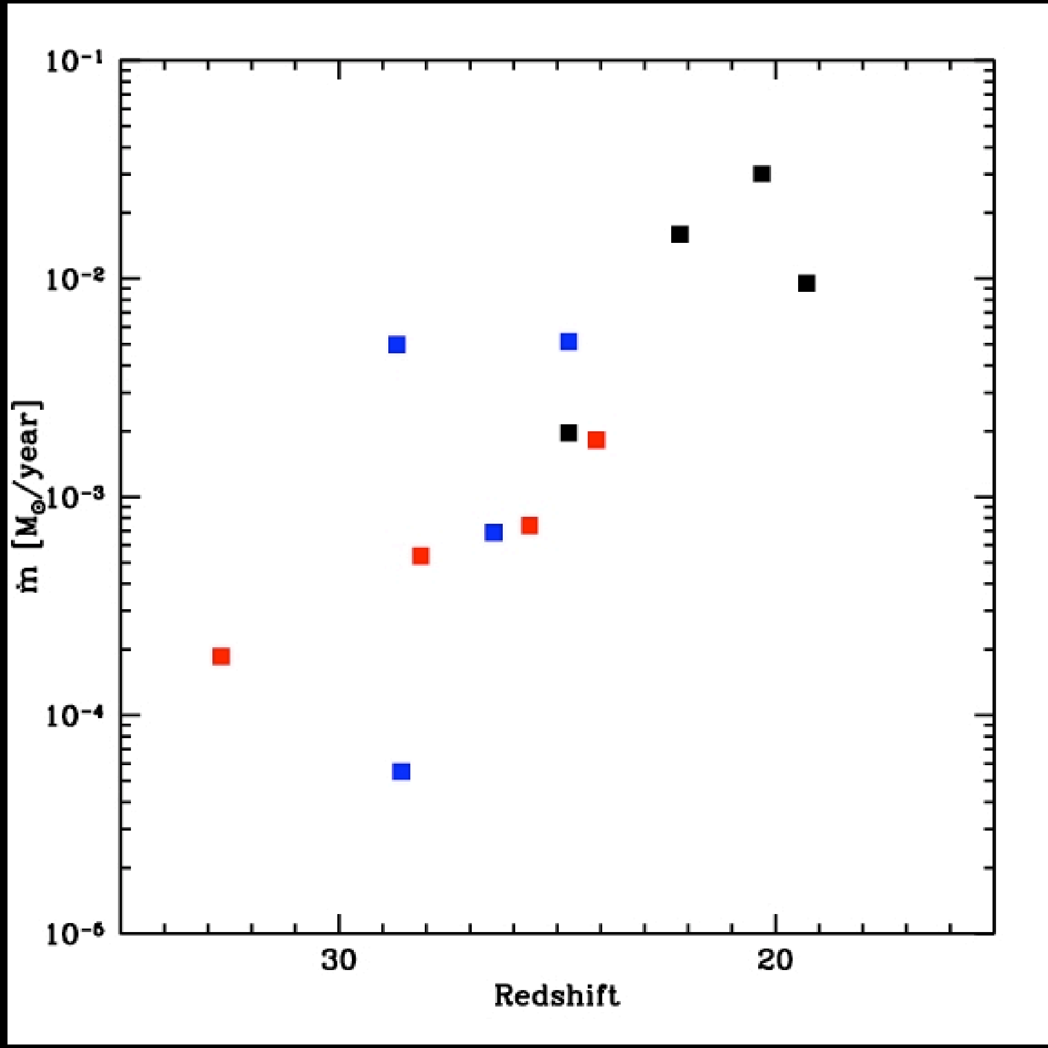
Accretion rate vs. halo collapse redshift

accretion rate



0.3 Mpc/h
0.45 Mpc/h
0.6 Mpc/h

Halo collapse redshift

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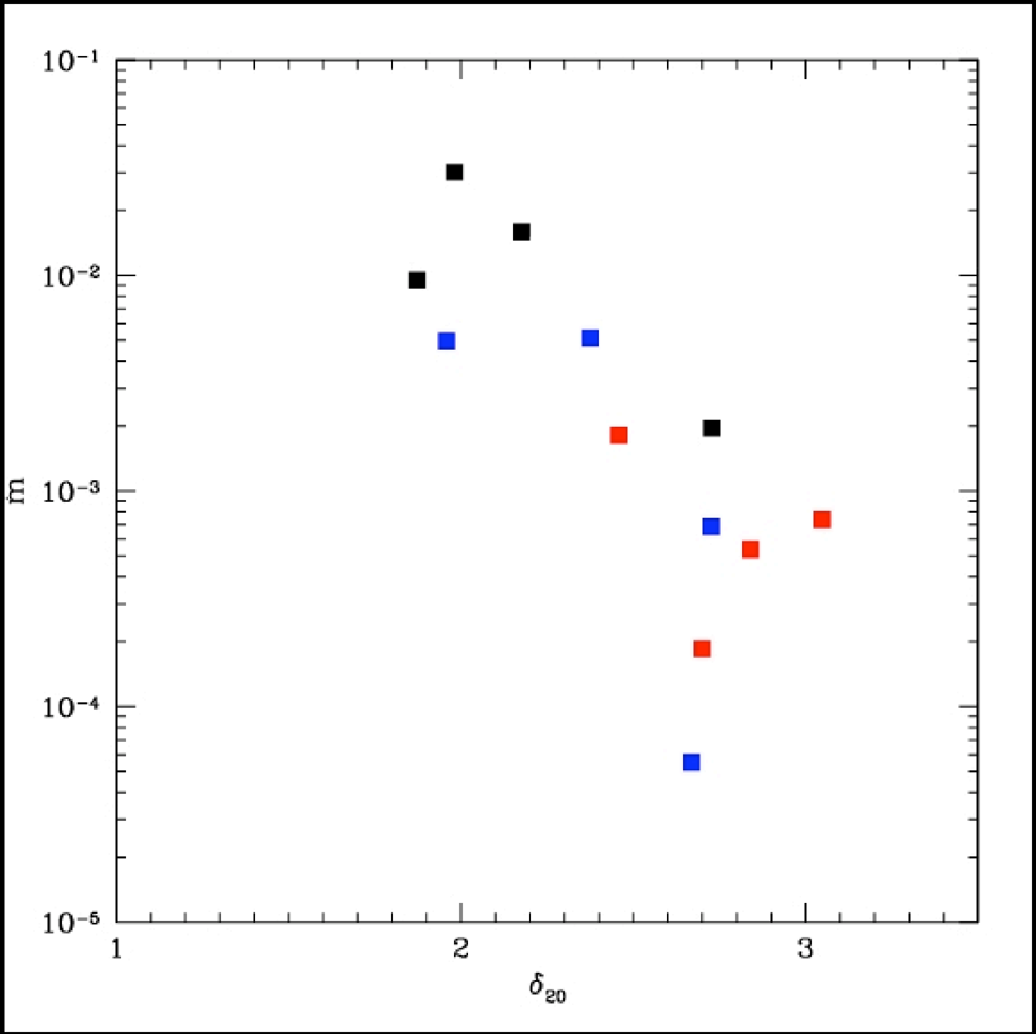
Accretion rate vs. halo environment

accretion rate



0.3 Mpc/h
0.45 Mpc/h
0.6 Mpc/h

Halo environment
(mean overdensity within 20 r_{vir})

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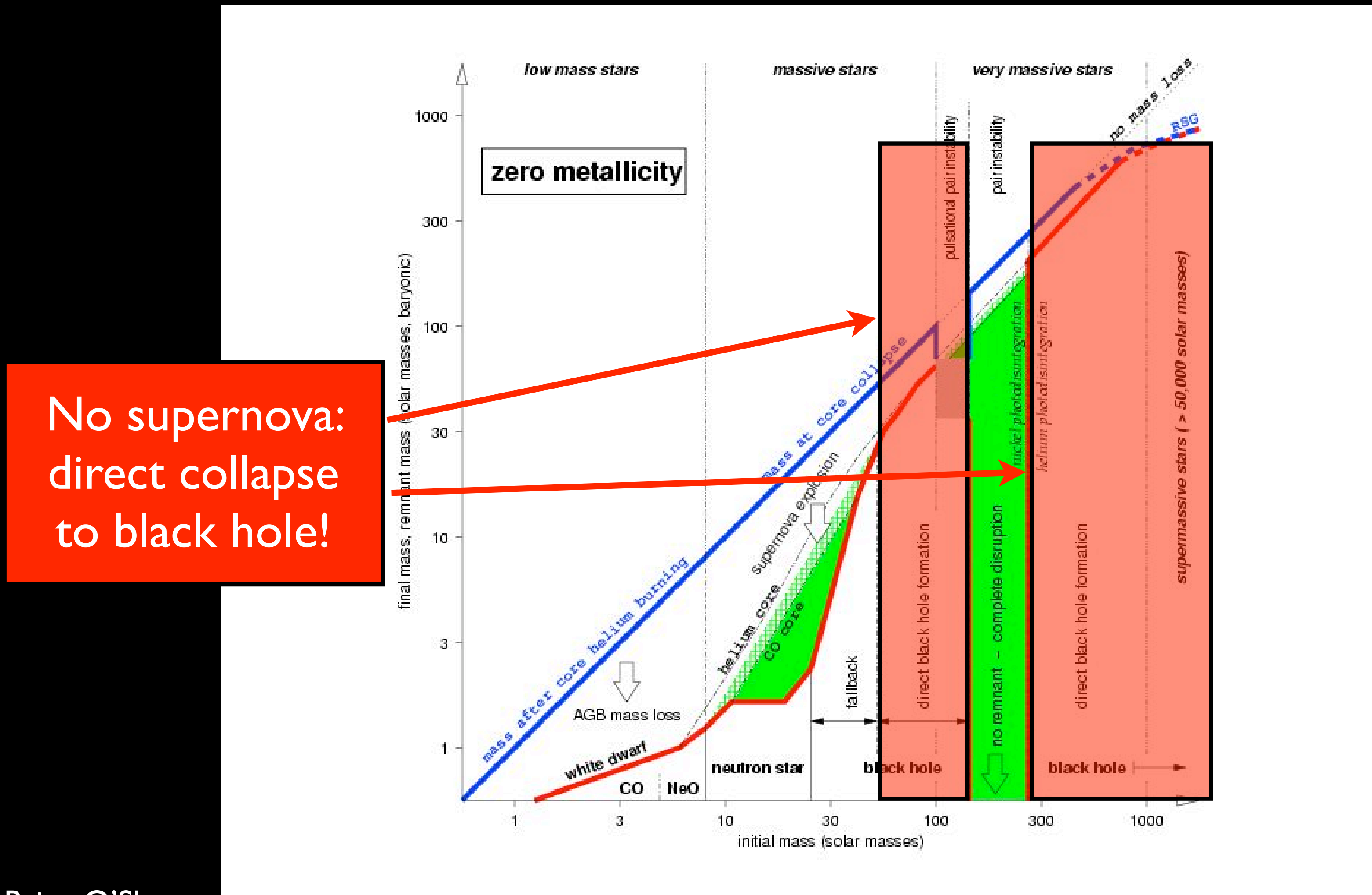
Population III HII regions



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O'Shea et al. 2005, ApJ, 628, L5-8

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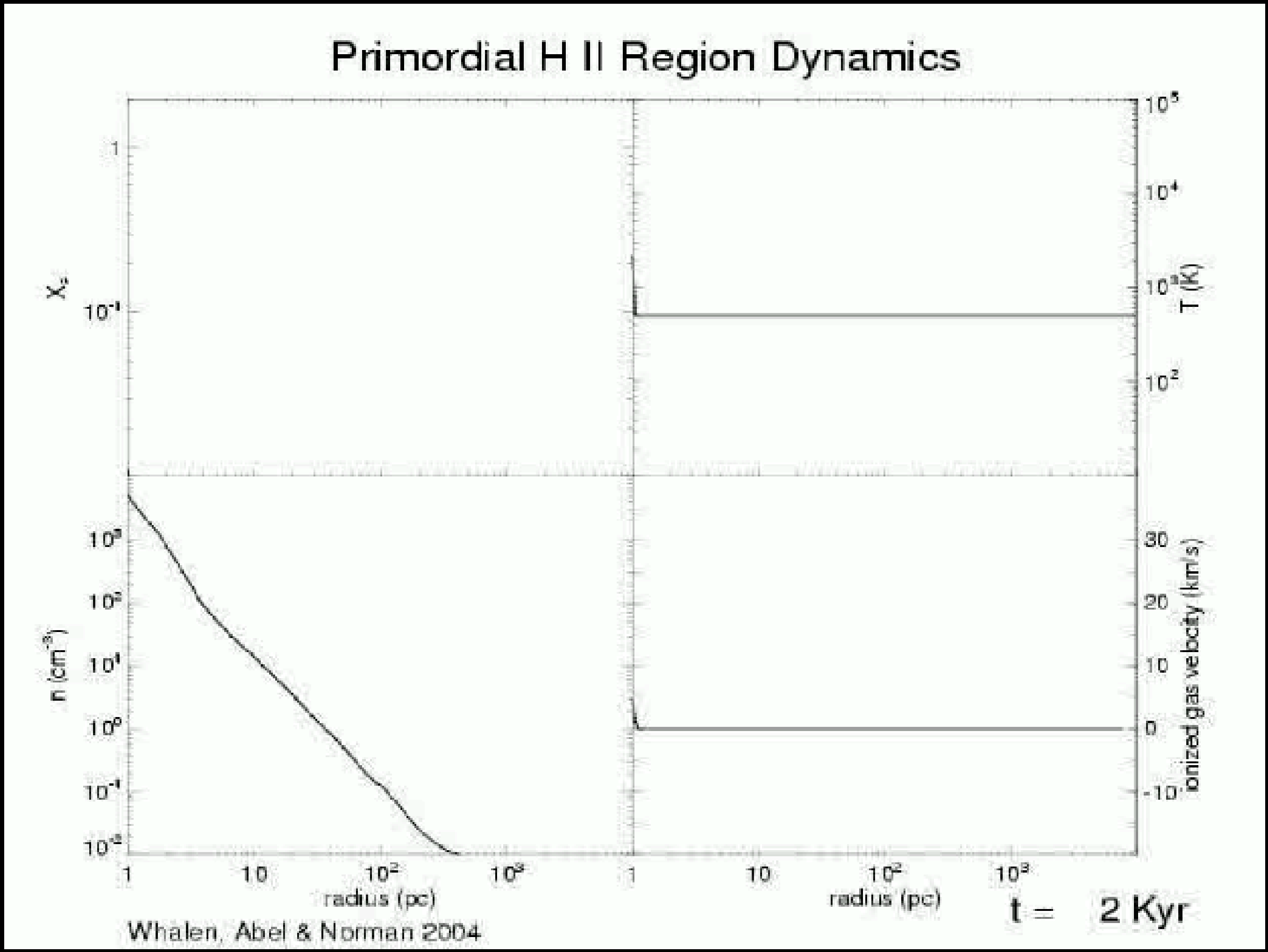
1D Evolution of Pop III HII Region



$M_* = 120\ M_\odot$
$t_* = 2.5$ Myr

Movie courtesy Dan Whalen (T-6/LANL)

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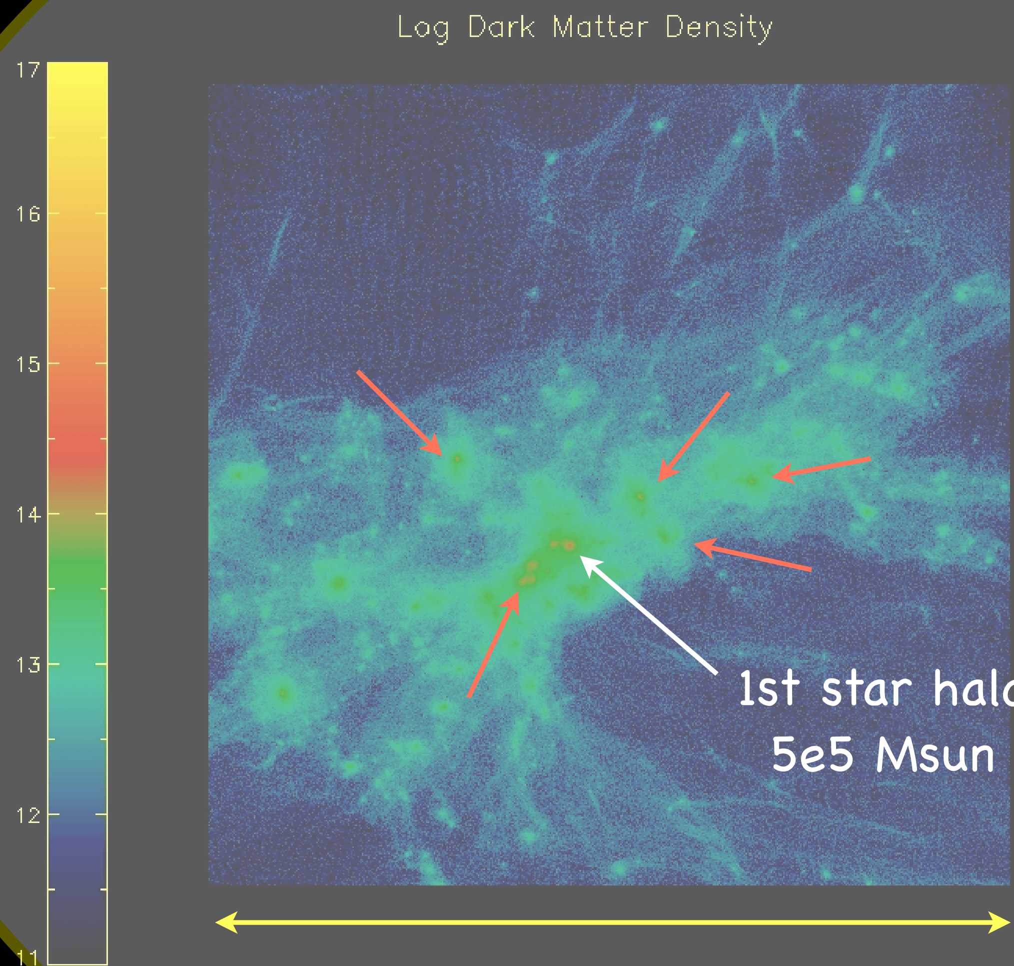
3D Calculations of HII region evolution

- Start with Pop III AMR sim. at $t = t_{*form}$
- Combine 1D and 3D results:
  - Whalen 1D result
  - 3D HII region extent: Abel & Wandelt ray-tracing code
- Turn AMR calculation back on with full nonequilibrium chemistry and allow sim. to continue until collapse of next protostar

The Cosmic Neighborhood

HII region (approx)



Halos w/ M > 1.5e5 Msun

1.5 kpc proper @ z=18

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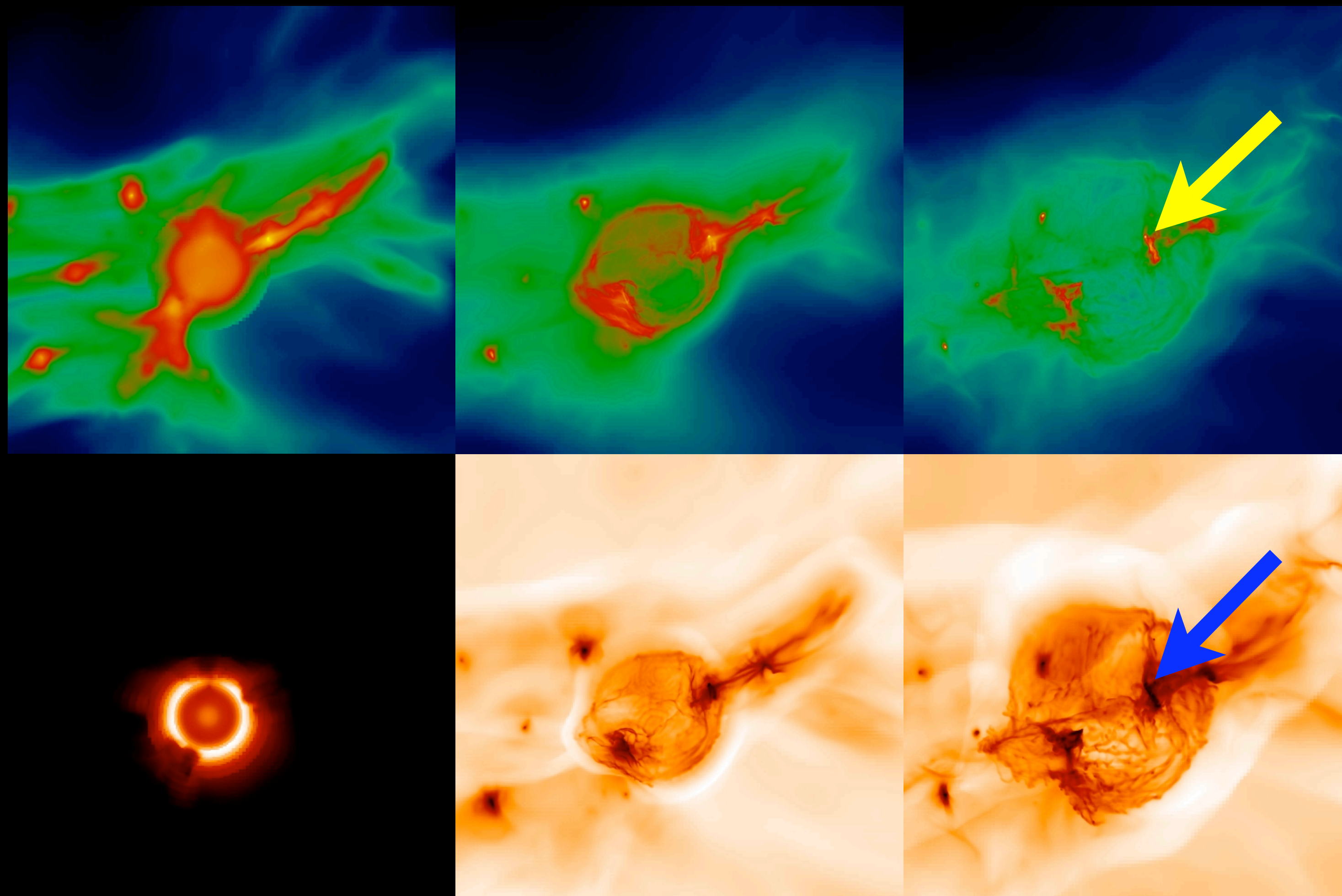
3D evolution of a Pop III HII region

baryon density

baryon temp.



$t - t_0 = 2.1$ Myr | $t - t_0 = 10.4$ Myr | $t - t_0 = 23$ Myr

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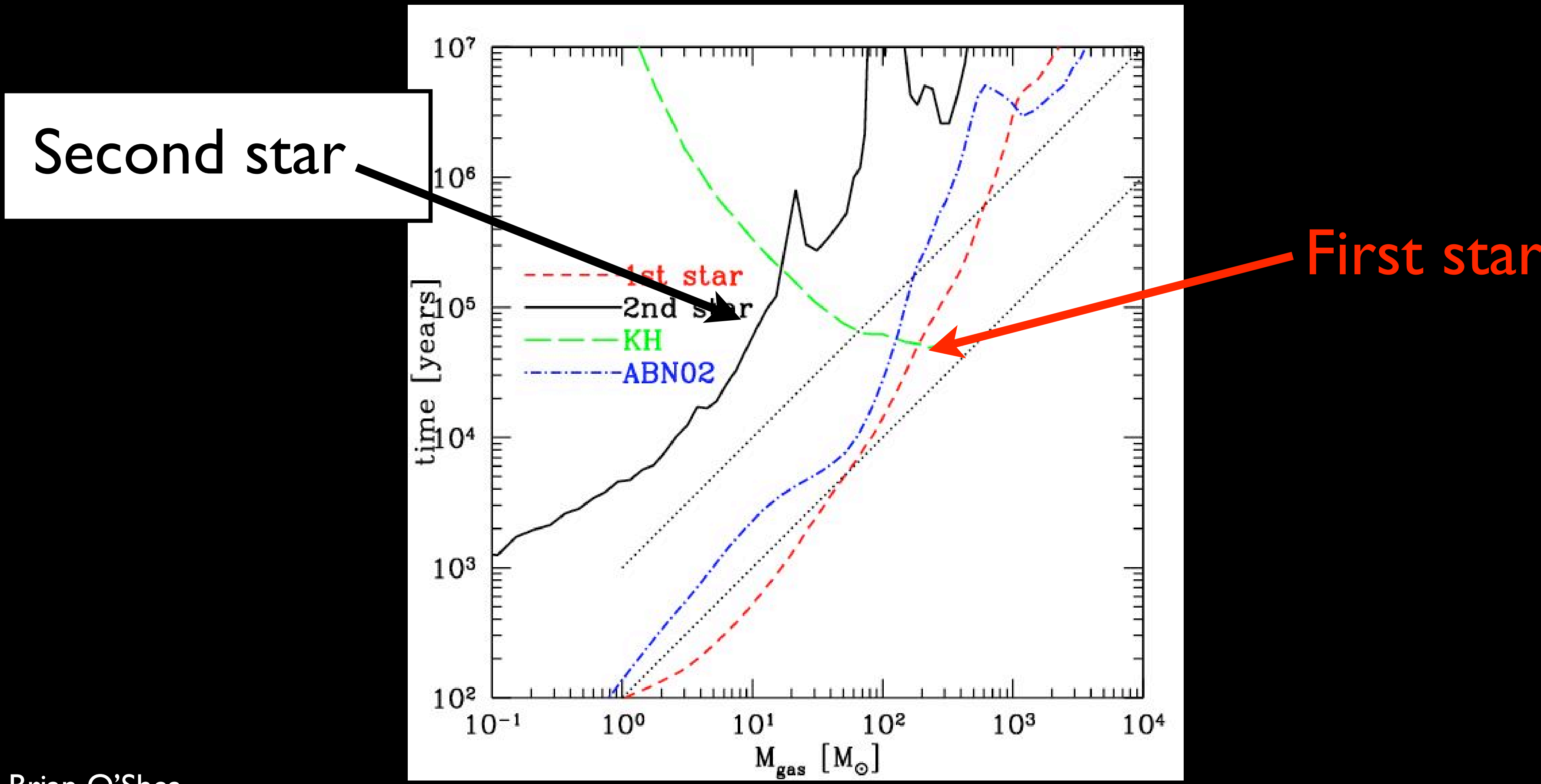
Accretion properties of the second star



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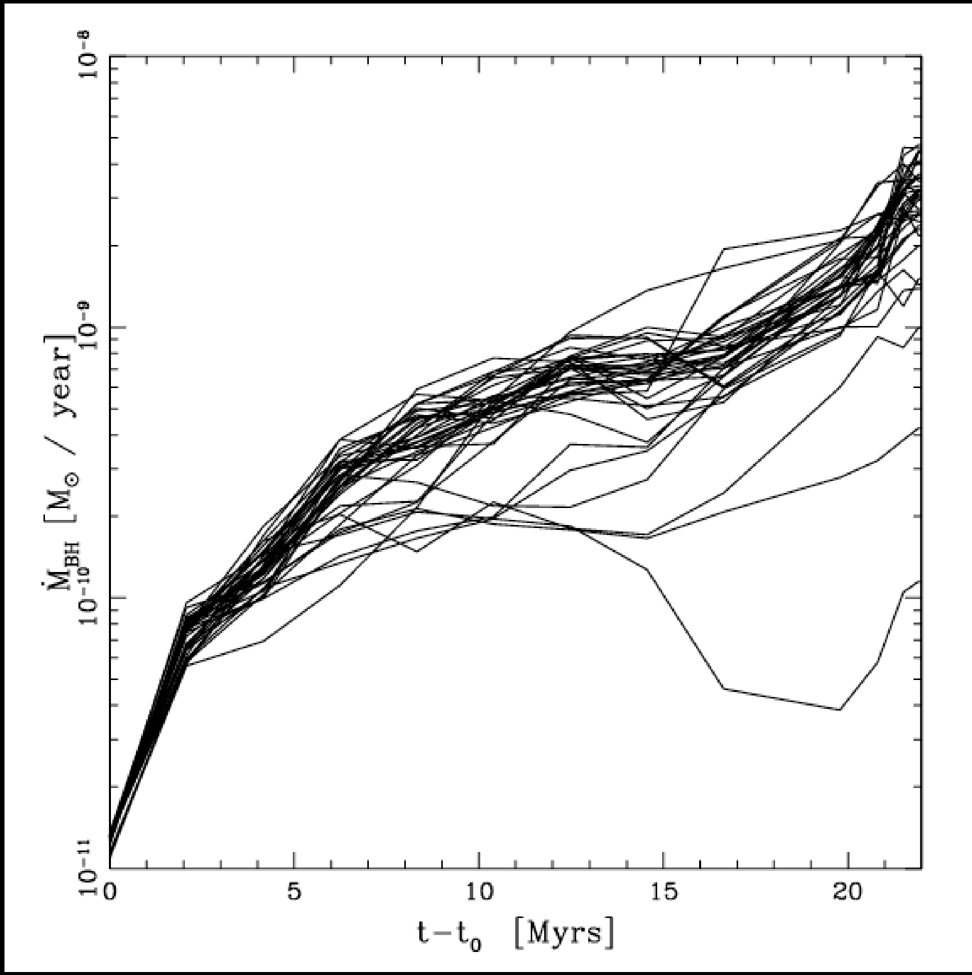
Estimated accretion rate onto black hole

10^{-8} M☉/yr

accretion rate

10^{-11} M☉/yr



Time (t-t*)

M_{bh} = 120 M☉

Assuming Bondi-Hoyle accretion

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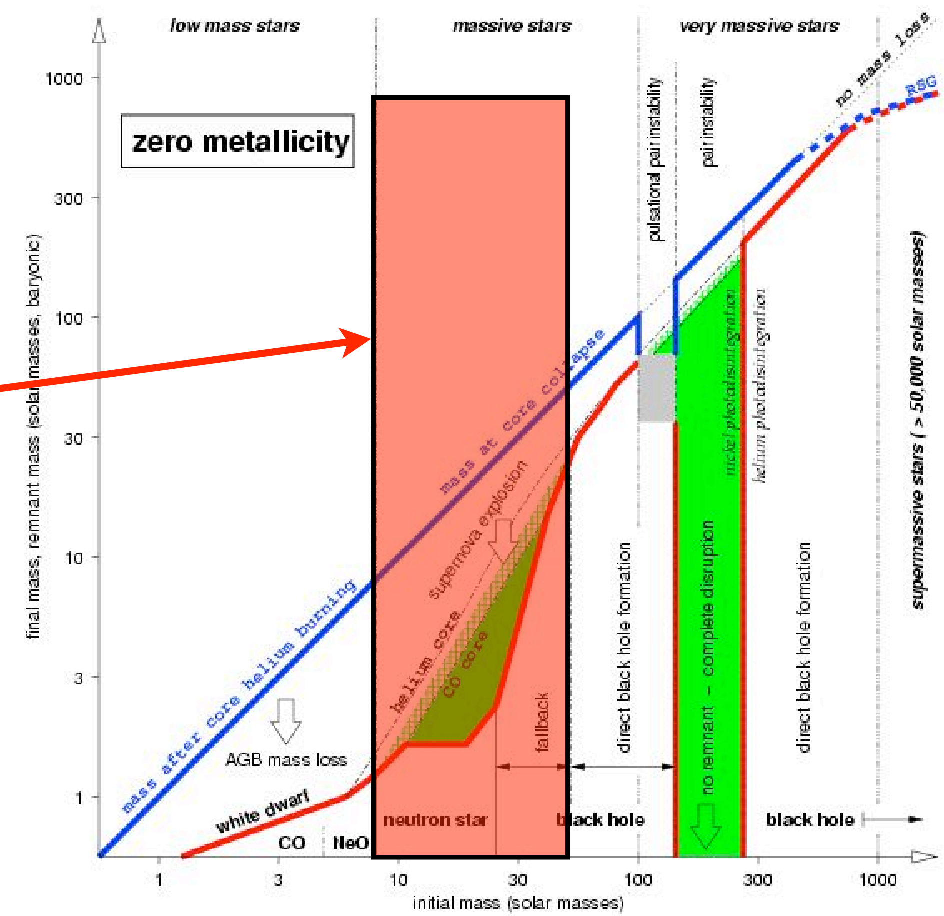
Population III Supernovae

Type II SNae



Type II
$E_{SN} \sim 10^{51}$ ergs

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O'Shea & Norman 2006, in prep.

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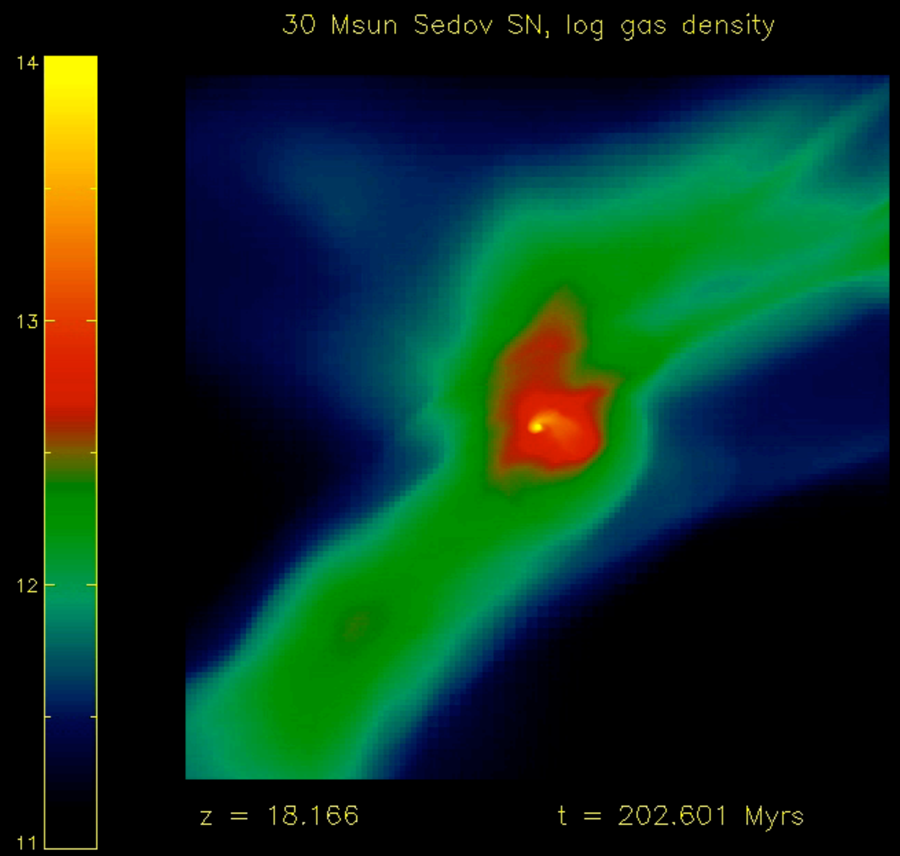
Projected log baryon density

$M_* = 30\ M_\odot$
$M_Z = 10\ M_\odot$
$E_{SN} = 1.2$ FOE



~350 pc (proper)

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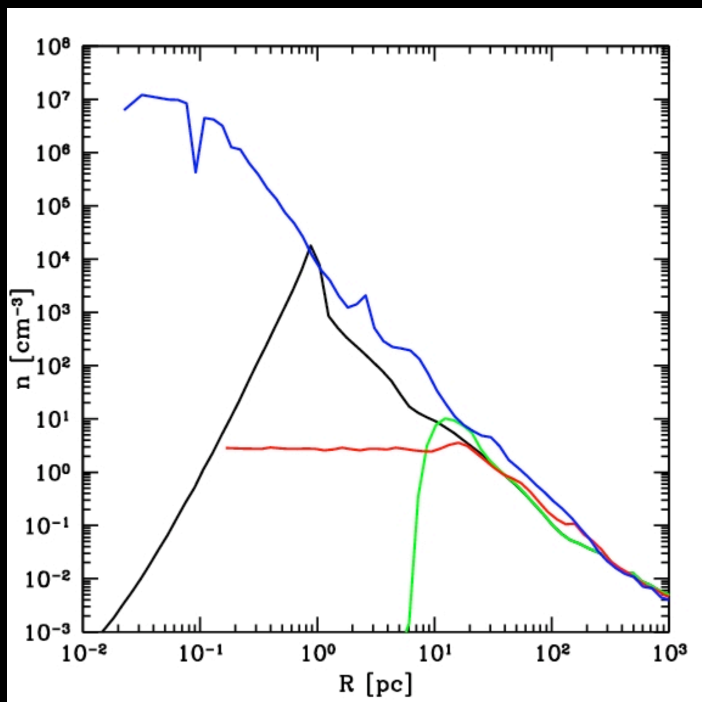
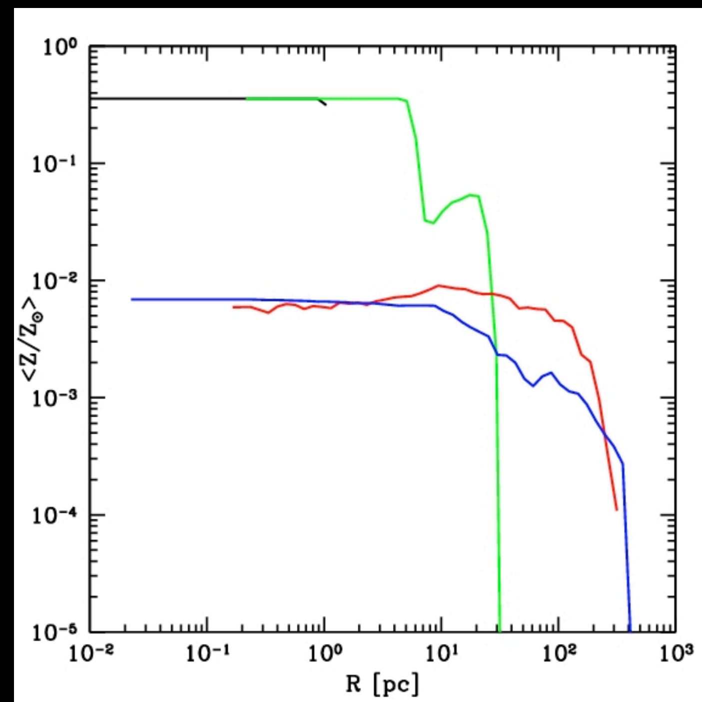
Supernova remnant evolution



Number density



Metallicity

$t = t_{SN}$
$t = t_{SN} + 4 \times 10^5$ yrs
$t = t_{SN} + 3 \times 10^7$ yrs
$t = t_{SN} + 7 \times 10^7$ yrs

Final polluted mass is
$\sim 2\times10^5\ M_\odot$, $\langle Z \rangle \simeq 0.003\ Z_\odot$

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Conclusions

1. Accretion rates onto primordial protostellar cores can vary by at least two orders of magnitude between simulations, suggesting a wider spread in stellar masses (~20-1000 $M_\odot$ using crude estimates)

2. This variance depends on redshift and also halo formation redshift/evolution history

3. HII regions and supernovae are very efficient at removing mass from halos and may delay black hole growth for >> 10^7 years

4. The M ~ 10^6 $M_\odot$ halo Pop III star formation paradigm seems unfavorable for SMBH progenitors - need to look more carefully at T_{vir} ~ 10^4 K halos (c.f. talk by John Wise yesterday)

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